

NASA Technical Memorandum 105341

1N-24
68720
P.12

Desktop Fiber Push-Out Apparatus

(NASA-TM-105341) DESKTOP FIBER PUSH-OUT
APPARATUS (NASA) 12 p CSCL 110

N92-16036

Unclas
G3/24 0068720

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December 1991

NASA



DESKTOP FIBER PUSH-OUT APPARATUS

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ABSTRACT

A desktop fiber push-out apparatus has been developed which offers the advantages of being compact, easy to operate, and inexpensive. A description of the design and operation of this apparatus is given.

INTRODUCTION

Fiber push-out testing has become an important tool for characterizing fiber debonding and sliding in fiber-reinforced composite materials. This information is important because the fiber debonding and sliding behavior affects the strength and toughness of the bulk composite. For the purposes of interface engineering, the fiber push-out test can be used to evaluate the effect of fiber coatings and composite processing conditions on both debonding and frictional shear strengths.

The basic requirement of a fiber push-out test is to be able to monitor the force at which a fiber resists the motion of an indenter which is driven by a constant displacement rate mechanism. Load versus time data establish the loads at which fiber debonding and sliding occur. Bright et al. (ref. 1) showed that an Instron testing machine could be used to control the indenter motion. Eldridge et al. (ref. 2) developed a similar apparatus with the added features of an improved indenter geometry and the addition of video imaging of the push-out process and acoustic emission detection to aid identification of the fiber debonding and sliding events.

Several factors, however, made the Instron-based apparatus unsuitable for routine use. The Instron load frame was not available on a dedicated basis for performing fiber push-out tests on demand. This presented two problems. The first was that testing could be performed only when the Instron load frame was available. Secondly, because of this equipment-sharing arrangement, the fiber push-out fixturing, optics, etc. had to be assembled before each test and dismantled after each test; this greatly increased the time required for testing. Since only small loads are needed for the push-out test (<50 N), it was decided that an alternate method of controlling the motion would be used which would be much more cost and space effective. This paper describes the design and use of a desktop fiber push-out apparatus.

DESIGN CONSIDERATIONS

The objective of the design was to produce an apparatus which would generate data equivalent to the data generated by the Instron-based apparatus, but with greater convenience. The primary considerations for maintaining quality data were (1) making the assembly as rigid as possible and (2) producing constant velocity motion, independent of load. Criterion (1) was important for achieving a low-compliance load train, avoiding the data artifacts observed in high-compliance assemblies (such as stick-slip behavior, load overshooting, and large energy release at debonding). Criterion (2) was important so that time could be taken as an accurate

reflection of displacement of the driving mechanism (displacement = velocity \times time). The greater convenience of the new design entailed (1) having a dedicated stand-alone apparatus always available, (2) a small footprint using a minimum of scarce floor space, and (3) ease of operation. Finally, the cost had to be less than purchasing a dedicated load frame.

APPARATUS

Figure 1 shows a schematic of the desktop fiber push-out apparatus. A photograph of the apparatus is shown in figure 2. Many of the components are the same as those used on the Instron-based apparatus. The major differences are a completely different mechanism for controlling vertical motion, and packaging of the apparatus in a much smaller frame.

Motion Control

Several motion or positioning controls are required for the push-out test: (1) controlled low-speed vertical motion during the push-out test, (2) coarse vertical positioning to reach the point where the test can be started, and (3) fine horizontal positioning to achieve fiber/indenter alignment.

The greatest change from the Instron-based apparatus is the use of a motorized vertical translation table to provide vertical motion of the sample. In this configuration the sample is pushed upward into the punch by a vertical translation stage¹ with 12.5 mm travel. The stage motion is driven by a dc motor-driven linear actuator² with a gear-reduction ratio of 5752:1. This motor is controlled by a servo controller³ which receives feedback from an optical encoder on the motor-driven linear actuator. The servo controller can be operated from its front panel, or from a personal computer via an RS-232 interface. The motor has a maximum speed of 8000 rpm, which produces a vertical stage speed of 5.795 $\mu\text{m}/\text{sec}$; during a push-out test a motor speed of 1200 rpm is used, which produces a vertical stage speed of 0.815 $\mu\text{m}/\text{sec}$. The very high gear reduction ratio was chosen in order to maintain constant low displacement rates under the varying loads which occur during a push-out test. Close to maximum speed is used to return the sample to its starting position at the end of each test, and for intermediate positioning before starting a test.

Because the maximum speed of the vertical stage is less than 6 $\mu\text{m}/\text{sec}$, a coarser vertical positioning mechanism was needed to bring the indenter and sample within 0.5 mm before using the vertical stage for final positioning. This was accomplished by mounting the indenter/load cell assembly on a telescoping post mount⁴ which is bolted in an inverted position to the underside of the structural frame. Loosening a split clamp by turning a knurled knob allows the indenter/load cell assembly to be moved manually in the vertical direction; tightening the split clamp locks the assembly in place.

¹Model MV80, Klinger Scientific Corp.

²Model BM25CC, Klinger Scientific Corp.

³Model DCS750, Klinger Scientific Corp.

⁴Model 380, Newport Corp.

Horizontal positioning was required for fiber/indenter alignment. This was achieved using a XY translation stage⁵ with 1-in. travel fine adjustment screw micrometers. No position readout was necessary as alignment was done visually using an optical microscope.

Load and Acoustic Emission Signals

Applied load was measured by a 50-lb capacity strain-gauge-based load cell⁶ which was mounted underneath the telescoping post mount and above the indenter. Bridge excitation and signal amplification were performed with a single channel amplifier/readout.⁷ A calibrated dc voltage output was used for data acquisition.

Acoustic emission was detected by a sensor⁸ mounted on a flat on the stainless steel adapter between the load cell and indenter holder. Excitation voltage and signal amplification were provided by a preamplifier⁹ and postamplifier.¹⁰ Signal readout was performed by a RMS meter¹¹ which also had a dc voltage output that was used for data acquisition.

Indenter

The indenter was a sintered tungsten carbide punch¹² with a 1/16-in. diameter shank which tapers down to a small-diameter flat-bottomed cylindrical tip. For the majority of testing, a 100- μ m diameter tip was used, although punches with tips in the range from 25 to 250 μ m have been used. This indenter configuration provides near-uniform loading of the fiber end, and allows push-out displacements over 1 mm without contact between the indenter and matrix.

Sample Support

The polished specimens were mounted on a support block using a small amount of superglue (cyanoacrylate ester). Several equally spaced parallel channels machined into the support block allow fibers to be pushed out without any resistance from the support block. Two different supports were used, one with channels of 300 μ m width and the other with channels of

⁵Model 425-1, Newport Corp.

⁶Model 41, Sensotec.

⁷Model 450D, Sensotec.

⁸Micro30, Physical Acoustics Corp.

⁹Model 1220A, Physical Acoustics Corp.

¹⁰Model AE1A, Physical Acoustics Corp.

¹¹Model 8920A, John Fluke Mfg.

¹²National Jet Corporation.

750 μm width. The support block with narrower channels was used in cases where sample bending over a wider channel would be significant.

Structural Frame

The structural frame was designed to be as rigid as possible while maintaining a compact size. The base was a 0.5 in. thick, 12-in. by 12-in. aluminum breadboard.¹³ The rest of the frame consisted of two 0.5 in. thick, steel support plates spanned by a 8.0-in. long, 1.0-in. thick steel crossbeam. The 15.0-in. tall frame included reinforcing gussets for added rigidity. The sample/translation table assembly was mounted to the baseplate, while the indenter/load cell assembly was mounted to the upper crossbeam.

Optics

Fiber/indenter alignment was performed by vertical and lateral positioning of the sample while watching the magnified image of the fiber and indenter on a TV monitor. This was achieved by using a long working distance (100 mm) stereo microscope¹⁴ with a CCD TV camera mounted via a MTV adapter to the phototube of the microscope. A zoom magnification of X6.3 and a phototube magnification of X5 produced a X31.5 magnification for the TV camera. A X5 primary magnification can be selected for initial coarse positioning by selecting the minimum zoom of X1. Further secondary magnification is produced by displaying on a TV monitor. Besides producing a TV image for fiber/indenter alignment, the image is also monitored and recorded during the push-out test itself by a VCR. Illumination is provided by fiber optic light guides.

Data Acquisition and Control

Data is stored in two formats: (1) computer data files of fiber push-out load and acoustic emission versus time and (2) video tape recording of a graphic representation of the load and acoustic emission signals versus time as they are acquired along with a TV image of the push-out process obtained through a stereo microscope as explained above, in a picture-in-a-picture type format.

A data acquisition system¹⁵ is used to collect data. This data acquisition system includes a 16 bit 50 kHz A/D module which is interfaced to an IBM-compatible AT/286 personal computer. Programming is done with Keithley KDAC500 software which creates an extension of Microsoft GWBASIC. A BASIC program titled KPLOT was written in this environment, using conventional BASIC programming for data manipulation algorithms, computer/operator interaction, graphics, data storage, and RS-232 communication; callable subroutines from the KDAC500 software were used which performed all the hardware interfacing tasks needed for data acquisition. Load and acoustic emission signals versus time were monitored, displayed on-screen both numerically and graphically as they were acquired, and stored in

¹³Model SA-11, Newport Corp.

¹⁴Model SZ6045, Olympus.

¹⁵System 575, Keithley Instruments.

computer files. In addition to data acquisition, KPLOT controls the motion of the vertical translation stage via RS-232 communication with the servo controller for the motor-driven linear actuator. The operator is prompted to perform initial positioning via the computer keyboard; when ready, the computer automatically controls the motion of the vertical translation stage during the test, and returns the stage to its home position at the end of each test.

A BASIC program titled ANALYZE was written for post-test analysis. This program allows the operator to move a cursor along the load/displacement curves and to read off load and time values at any points of interest.

Video monitoring and recording of the push-out test provides a method for correlating events on the fiber push-out load and acoustic emission versus time curves with observable events occurring on the TV image. A video mixer (Telecomp 2000) is used to display and record on video tape a composite image of the computer-generated graphic and numerical display of the data as they are acquired with a window (picture-in-a-picture) displaying the TV image from the TV camera mounted on the stereomicroscope examining the push-out process (see fig. 3). In this way, the video tape can be reviewed, and the operator can confirm whether a load drop corresponded to initial fiber movement, or, for example, a matrix crack. In some cases, a second microscope with a TV camera is used to provide a second window on the TV display showing the fiber coming out of the bottom of the sample. By monitoring both the top and bottom fiber ends, it has been shown that, in some cases, the top end of the fiber is displaced well before the bottom end of the same fiber is displaced.

Cost

The total cost of all components was about \$20K. Of this amount, only \$6.2K was spent on the vertical motion control and load cell and associated electronics. Thus, the cost tradeoff of the desktop apparatus versus the Instron-based apparatus should be \$6.2K for the desktop apparatus versus the cost of an Instron load frame with load cell.

Many of the features of the desktop fiber push-out apparatus could be sacrificed while still providing the most important information, the load/displacement data. Such a system could be assembled for a cost of about \$11K, forgoing computer data acquisition, AE detection, and video mixing and recording.

RESULTS

Figure 4 shows typical load and AE versus displacement data generated by the desktop fiber push-out apparatus. Interpretation of this type of plot has been previously described (ref. 2).

CONCLUSIONS

A desktop fiber push-out apparatus has been successfully designed, assembled, and tested. It has been shown to generate data equivalent to that generated by an earlier Instron-based apparatus, but with advantages of greater convenience of operation, less floor space, and lower cost.

APPENDIX A

INSTRUCTIONS FOR OPERATION OF DESKTOP FIBER PUSH-OUT APPARATUS

The following gives a step-by-step guide for performing fiber push-out tests.

1. Sample mounting: Place properly cut and polished sample across grooves on sample support block. For samples with low fiber volume fractions, try to position sample so a reasonable number of fibers are over the grooves. Apply (a pin or needle makes a good applicator) very small amount of superglue to ends of sample. Try not to allow glue to flow underneath sample. When glue sets enough to hold sample, apply very small amount of glue to sample sides, including surfaces between grooves, but not where sample spans grooves. Best approach is to place small drop of glue on support surface and then drag or "coax" glue towards edge of sample.

2. Sample mapping: Take optical micrograph of mounted sample (x10 to x50 range). Make photocopy of micrograph and mark off areas of sample which span the grooves in the support block. Only the fibers in these areas are available for push-out testing.

3. Push-out data form: Fill out top of push-out data form; include any sample I.D. information, thickness, and computer file name. Fill out appropriate sections during testing.

4. Mount sample plus support block onto upper translation stage using 1/4-in.-20 cap screws; tighten with Allen wrench.

5. Power-up: Turn on main power on base of computer monitor. Turn on Klinger motor controller/driver. Turn on TV monitor and video mixer. Turn on acoustic emission amplifier, RMS meter, load cell power/read-out, TV camera, and fiber optic light source.

6. VCR start-up: Turn power on VCR. Insert tape and fast forward to end of previously recorded tape.

7. Punch selection: Make sure appropriate diameter punch is in punch holder. To remove punch, loosen set screw on load cell adapter and pull out punch holder. Loosen set screw on punch holder and pull out punch (grasp shank of punch with tweezers and pull).

8. Acoustic emission transducer: Make sure mini-coax cable from preamplifier is connected to transducer. Transducer is glued to flat surface of connecting fixture between load cell and indenter holder.

9. Lowering of punch/load cell: The punch/load cell assembly is lowered using the telescoping post mount which is mounted upside-down underneath the support frame. **DO NOT TURN KNURLED KNOBS UNLESS YOU ARE SUPPORTING WEIGHT OF LOAD CELL!!** Turning either knurled knob counterclockwise releases the whole assembly. Support the load cell with your left hand as you turn one of the knurled knobs counterclockwise with your right hand. **DO NOT RELEASE LOAD CELL UNTIL KNURLED KNOB IS RETIGHTENED!!** Guide load cell downward until punch is almost touching sample. You may need to position sample underneath punch by using manual micrometers on X-Y stage. Try to get punch as close as possible to sample since motorized vertical positioning is very slow. When

you have finished positioning punch, tighten (clockwise) knurled knob with your right hand and release load cell with your left hand.

10. Microscope set-up: Illuminate sample with fiber optic light guides. Set microscope magnification to lowest possible using zoom ring. Look at TV monitor and try to locate sample plus punch. Focus microscope. Video mixer (Telecomp 2000) should be set with MIX/OVERLAY switch on MIX, the COMPUTER/VIDEO/OFF switch on OFF, and the video mix dial completely counterclockwise to VIDEO. Reposition base as needed to center punch bottom on screen. Increase magnification and repeat. Adjust with light guide position to get best possible light reflection. At highest magnification try to get punch bottom in upper left quadrant of screen.

11. Load cell calibration: Make sure punch is not touching sample and that nothing is leaning against load cell assembly (light guides, for example). Load cell readout on front panel should be 0.00 lb. If not, use small screwdriver to adjust zero potentiometer on front panel of load cell conditioner/readout (on bottom). Next, check shunt calibration by depressing shunt button. The front panel display should be 24.62 lb. If not, adjust gain potentiometer with screwdriver while continuing to keep shunt button depressed. The load cell is now calibrated.

12. Indexing fibers: Compare image of sample on TV monitor with photocopy of optical micrograph. Look for distinguishing features such as scratches, touching fibers, dirt, etc. In this way match at least one fiber location on the TV monitor with one on the micrograph. Then by counting along a row of fibers, you can match or index the fibers you intend to test (those fibers must be over channels, as you have already marked on the micrograph photocopy). Mark each fiber you test on the photocopy with a corresponding identification (i.e., number 1 for first fiber tested) so that you have record of which test corresponds to which fiber.

13. Setting up data acquisition: For computer monitor display, the L-COM Transfer Switch should be set on 2. Follow directions on computer screen: type "kdac500 kplot" to enter data acquisition program. Proceed to type sample identification, thickness, and fiber number. Answer whether you wish to record acoustic emission data. Respond to request for length of test (180 sec is usually sufficient) and dwell time (50 msec is standard)—do not type units. Enter maximum load cutoff. This is the upper load limit you choose at which point the test will be automatically terminated (this is a safety feature to prevent accidental overloading of the punch). A 100 μ m diam. punch should easily reach 30 N, and usually up to 35 N. You are now ready to start sample positioning sequence.

14. Sample positioning sequence: Upon hitting <enter>, you can control the movement of the vertical translation stage from the computer keyboard. Stage movement is initiated by depressing and releasing the up and down cursor keys (for slow movement) and the <page up> and <page down> keys (for fast motion). Stopping the stage movement is accomplished by depressing the <home> key. The purpose of the first part of the sequence is to determine the home (or return) position, which is the position the sample will return to at the end of each test. The best position is the one at which you want to do your punch/fiber alignment. A good choice is a position where the bottom-front of the punch appears to be coincident with the back of the fiber to be tested while the rear-top of the punch reflection is coincident with the front edge of the fiber to be tested. You will need to manually adjust the x-y stage to find this position. When you have reached the optimum home position and have halted vertical motion, type <enter> to proceed to the final positioning sequence.

Use the <page up> and then the cursor up keys to bring the fiber to be tested as close as possible to the bottom of the punch. Use the <home> key to stop motion. If you notice a non-zero load read-out, you have gone too far and must lower the sample. Hit <enter> after you have halted motion with the punch almost touching the fiber. Make sure the punch looks reasonably well centered over the fiber. You are now ready to begin the test.

15. Video mixing set up: Throw L-COM Transfer Switch to selection #1 to transfer computer screen output to TV monitor. On Telecomp 2000 video mixer, make sure MIX/OVERLAY switch is on MIX and set COMPUTER/VIDEO/OFF switch to VIDEO. Adjust MIX BALANCE so you can see video window. Adjust sides of video window to frame fiber and punch bottom, preferably in upper left quadrant of monitor screen. Adjust MIX BALANCE again so that computer output is easily readable.

16. Starting push-out test: Start recording on VCR and then hit any key on the computer keyboard. Test will automatically proceed until you hit <S> on the keyboard or until load maximum is reached.

17. Stopping push-out test: When the test has proceeded to a point after debonding where there is not much change, hit <S> to stop the test. The sample will automatically return to its home position. Stop recording on the VCR. Record the tape position on your push-out data sheet for later reference.

18. Storing data: Answer "Y" when the program asks if you wish to store data. Next, provide the file name for that test (without an extension). For example, 08JE12 (8th sample by Jeff Eldridge, 12th fiber on that sample). Computer may take up to 1 min to store data on hard disk.

19. Continued testing: Respond to computer program and indicate new fiber number. Use manual adjustment of X-Y stage to relocate another fiber underneath punch. Mark fiber identification on micrograph photocopy. Repeat steps 14,16,17, and 18. If no readjustment is necessary for selecting the home position, just hit <enter> for that step in the sample positioning.

20. Testing other samples: Manual adjustment of the load cell/punch assembly (see step 9) will usually be necessary to accommodate different thickness samples.

21. End of session: After last fiber tested, respond to program that you do not wish to test any more fibers or samples. Raise the punch/load cell assembly to maximum height (reverse of step 9). Rewind video tape and remove from VCR. Copy data files from hard disk to your own 5¼-in. floppy disk (for example: COPY 08JE??,PRN A:—this DOS command copies all files of type 08JE____.PRN to the floppy disk in drive A:). Turn equipment power off (reverse of steps 5 and 6). Remove your sample with support block from the upper translation stage. Soak sample plus support block in acetone to remove sample. Return support block.

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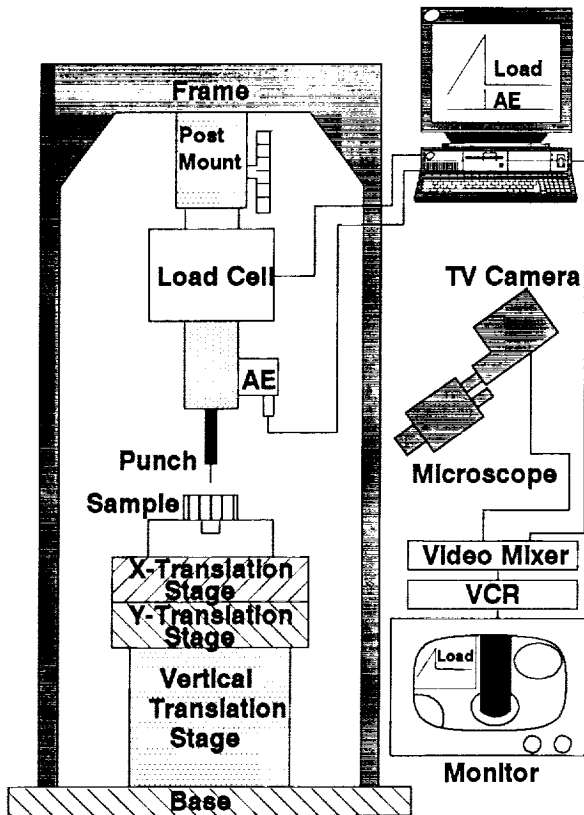


Figure 1.—Schematic representation of desktop fiber push-out apparatus.



Figure 2.—Photograph of desktop fiber push-out apparatus.



Figure 3.—Typical TV display during fiber push-out test. Display shows computer-generated display of load and acoustic emission versus time along with a window showing the punch pushing out the fiber being tested.

Fiber Push-Out Data SiC/RBSN

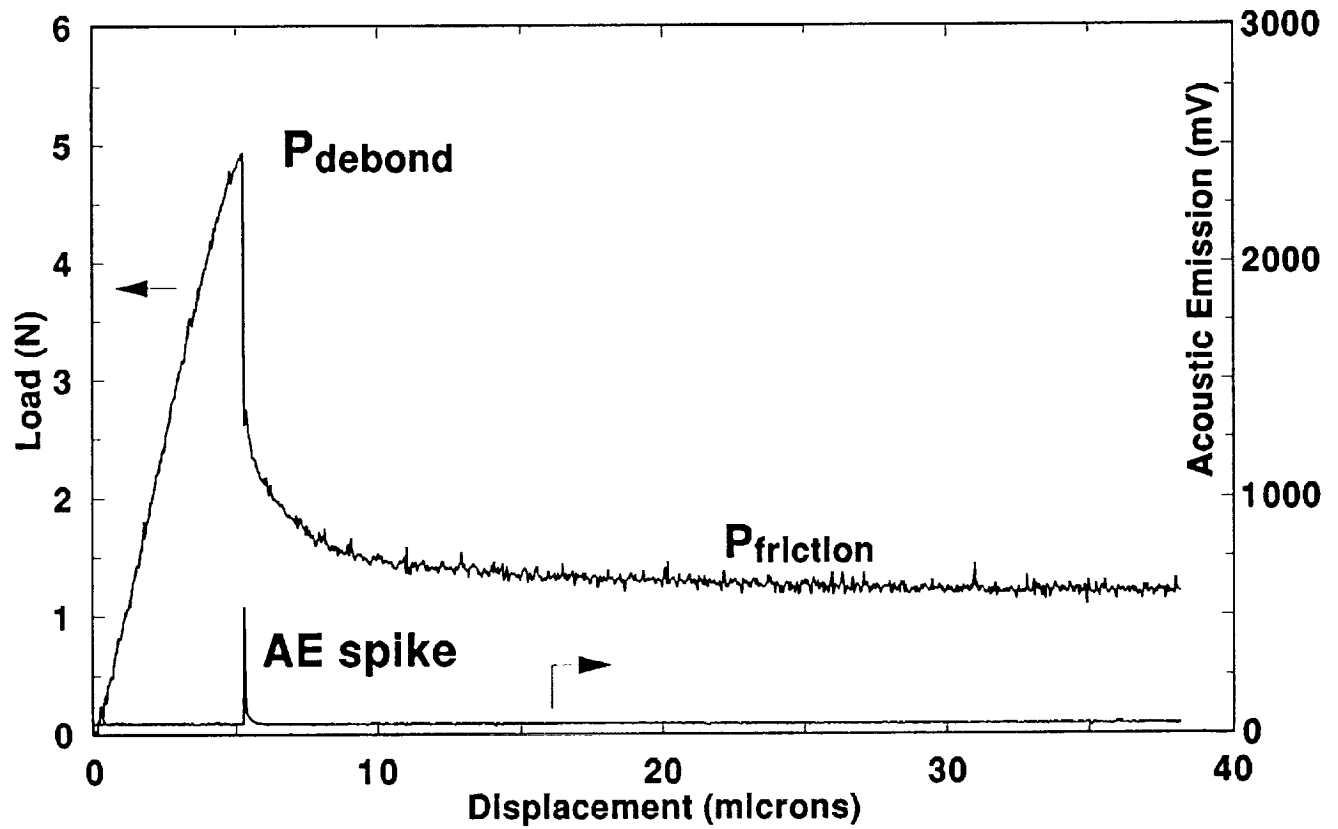


Figure 4.—Typical data generated by desktop fiber push-out apparatus. Specimen was 2.28 mm thick SCS-6 SiC fiber reinforced reaction-bonded Si_3N_4 (SiC/RBSN). The upper curve represents load versus vertical stage displacement. The debond load, P_{debond} , is taken to be the load preceding the sudden load decrease. The frictional sliding load, P_{friction} , is taken to be the stable load reached after debonding. The lower curve represents acoustic emission (AE) signal versus vertical stage displacement.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE December 1991		3. REPORT TYPE AND DATES COVERED Technical Memorandum
4. TITLE AND SUBTITLE Desktop Fiber Push-Out Apparatus			5. FUNDING NUMBERS WU-510-01-04	
6. AUTHOR(S) Jeffrey I. Eldridge				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191			8. PERFORMING ORGANIZATION REPORT NUMBER E-6709	
9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, D.C. 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA TM-105341	
11. SUPPLEMENTARY NOTES Responsible person, Jeffrey I. Eldridge, (216) 433-6074.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 24			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) A desktop fiber push-out apparatus has been developed which offers the advantages of being compact, easy to operate, and inexpensive. A description of the design and operation of this apparatus is given.				
14. SUBJECT TERMS Shear strength; Solid-solid interfaces			15. NUMBER OF PAGES 12	
			16. PRICE CODE A03	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	